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SUMMARY OF THE RESULTS OF ANALYSIS OF OBSIDIAN ARTIFACTS FROM THE MAYA LOWLANDS

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Abstract

The analytical method of X-ray fluorescence spectrometry has been used to analyze obsidian artifacts from Cerros, Belize and from Yaxchilan, Chiapas, Mexico. The results of these analyses are compared to the results of analysis of obsidian geologic sources using graphical and statistical methods in order to identify the probable source from which the obsidian for the artifacts came. These results are then summarized along with results of analysis by others of obsidian artifacts from several archaeological sites in the Lowland Maya area. Using these data, possible trade routes and how they may have changed through time have been postulated.

KEY WORDS: X-ray fluorescence analysis; obsidian; Maya exchange routes; obsidian trade; Maya archaeology; Cerros, Belize; Yaxchilan, Chiapas; Mesoamerican archaeology.

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Introduction

This paper reports the results of analysis of obsidian artifacts from Cerros, Belize and from Yaxchilan, Chiapas, Mexico -- two Maya Lowland archaeological sites (Figure 1). Also, the results of these analyses are compared to the published results of analyses of obsidian artifacts from several other archaeological sites in the Maya Lowlands. The apparent patterns of exchange and how they changed through time are also discussed.

Obsidian was a valuable and important resource that the Maya Indians used to make very sharp weapons and tools. All levels of Maya society appear to have had access to and used obsidian. However, because there are no known geologic sources of obsidian in the Lowland Maya region, the material was rather scarce and had to be transported by human carriers for long distances -- over mountain passes, down rivers, and through the jungles. These routes over which obsidian was transported into the Lowland Maya region appear to have become important to the Maya for communication and trade. Because each geologic source of obsidian appears to have a unique trace element composition it is possible -- using analytical methods such as X-ray fluorescence -- to study the trade routes and how they may have changed through time.

In this paper the methods used for the analysis of obsidian will be described as well as how the artifacts were correlated to the geologic sources. Then the results of analysis will be presented. Finally the results of analysis of the Yaxchilan and Cerros obsidian artifacts will be discussed in light of data available from the analysis of obsidian artifacts from other sites in the Maya area.

These analyses were undertaken in an effort to 1) better understand the procurement and utilization of obsidian by the prehistoric peoples of the Maya area, and 2) to contribute to the growing literature on obsidian use and procurement in prehistoric Mesoamerica (Asaro et al. 1973, 1978; Charlton and Spence 1982; Clark 1981; Clark and Lee 1984; Cobean et al. 1971; Graham et al. 1972; Hammond 1972, 1976; Hurtado de Mendoza 1973; Hurtado de Mendoza and Jester 1978; Neivens et al. 1983; Nelson 1980, 1981b; Nelson et al. 1977, 1978, 1983; Nelson and Voorhies 1980;

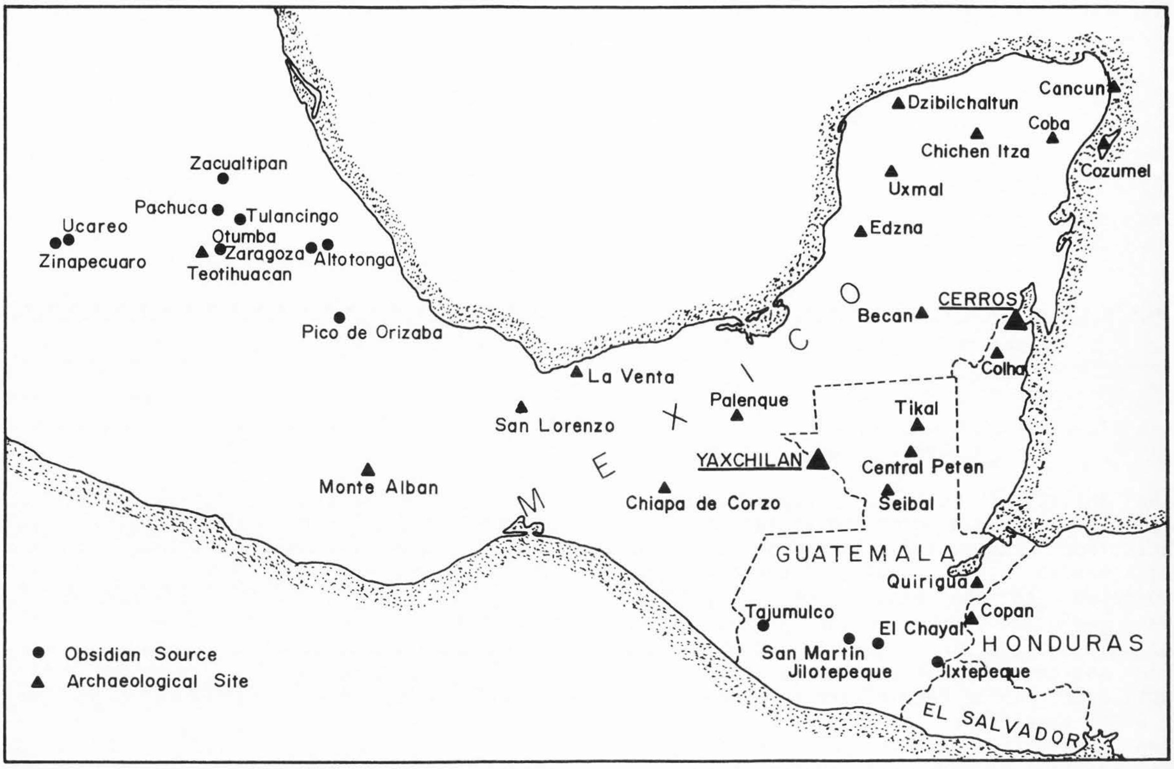

Figure 1. Map of Mesoamerica showing the approximate location of Cerros, Yaxchilan and other archaeological sites as well as the location of several sources of obsidian.

Rice 1984; Sidrys et al. 1976; Stross et al. 1976a, 1976b, 1983; Zeitlin 1978, 1979, 1982; Zeitlin and Heimbuch 1978).

Traditionally archaeologists have separated Maya prehistory into three periods of time -- roughly according to different stages of development. For example the Preclassic period (1000 B.C. - A.D. 250) represents pre-urbanization and the developmental period. The Classic period (A.D. 250 - 1000) represents centralized government and a highly urban society. The Postclassic period (A.D. 1000 - 1521) represents the fall of many urban centers and a movement of population centers from these centers to the northern Yucatan Peninsula and along the Gulf and Caribbean coasts. These three periods of time are usually further divided by archaeologists in order to identify more precisely the time of appearance and disappearance of different cultural traits. Dates are assigned to the obsidian artifacts according to their association to other cultural material (such as ceramics) and to organic material that can be radiocarbon dated.

Methods of Analysis

Several methods of instrumental analysis of obsidian have been used by various authors (Nelson 1981a). However, in this study the analysis of 10 obsidian artifacts from Cerros and 12 artifacts from Yaxchilan was conducted using X-ray fluorescence spectrometry with wavelength dispersive detection (Nelson 1984; Nelson et al. 1983). X-ray fluorescence uses monochromatic X-rays from a chromium X-ray tube or a tungsten X-ray tube (depending on the elements being analyzed) to furnish the energy necessary to cause the electrons in the atoms to be ejected from inner energy levels to other less stable levels. As electrons in adjacent higher energy levels fall back into the charge vacancy created in the innermost levels, fluorescent X-rays are emitted. The energy or wavelength of these fluorescent X-rays are unique for each element. Therefore, by determining which wavelengths or energies are emitted, the elements in the sample can be identified. The intensity of the fluorescent X-rays allows one to determine the quantity of the element present in the sample.

The detection of the fluorescent X-rays was accomplished using wavelength dispersive methods. This detection system utilizes diffraction crystals to disperse the fluorescent X-rays of various wavelengths so that the detector can measure each one separately. This is done by setting the diffraction crystal to the proper two theta (2θ) angle (Figure 2) as described by the Bragg equation ($n\lambda = 2d \sin\theta$). The elements present in the sample can then be identified.

The analyses were performed using a Philips PW1410 vacuum path X-ray fluorescence spectrometer equipped with a high-precision, five-position diffraction crystal changer and a semi-automatic programmable goniometer controller. Power to the X-ray tube is supplied by an ultra stable three kilowatt Philips 1140 generator. Table 1 lists the instrumental settings used for the analysis of each element. The analyses were performed in

Table 1. Instrumental settings used for the analysis of obsidian sources and artifacts.

Element	Analytical Line	2θ	Analyzing Crystal	X-ray Tube	Generator kV	Generator mA	Counting Time
Rb	Kα	26.62	LiF200	W	50	20	40 sec
Sr	Kα	25.15	LiF200	W	50	20	40 sec
Y	Kα	23.80	LiF200	W	50	20	40 sec
Zr	Kα	22.55	LiF200	W	50	20	40 sec
Nb	Kα	21.40	LiF200	W	50	20	40 sec
MnO	Kα	62.97	LiF200	W	50	20	40 sec
Fe_2O_3	Kα	57.52	LiF200	Cr	50	20	40 sec
TiO_2	Kα	86.14	LiF200	Cr	50	20	40 sec
Ba	Lα	87.17	LiF200	Cr	50	20	40 sec
Na_2O	Kα	54.38	RAP	Cr	40	60	100 sec

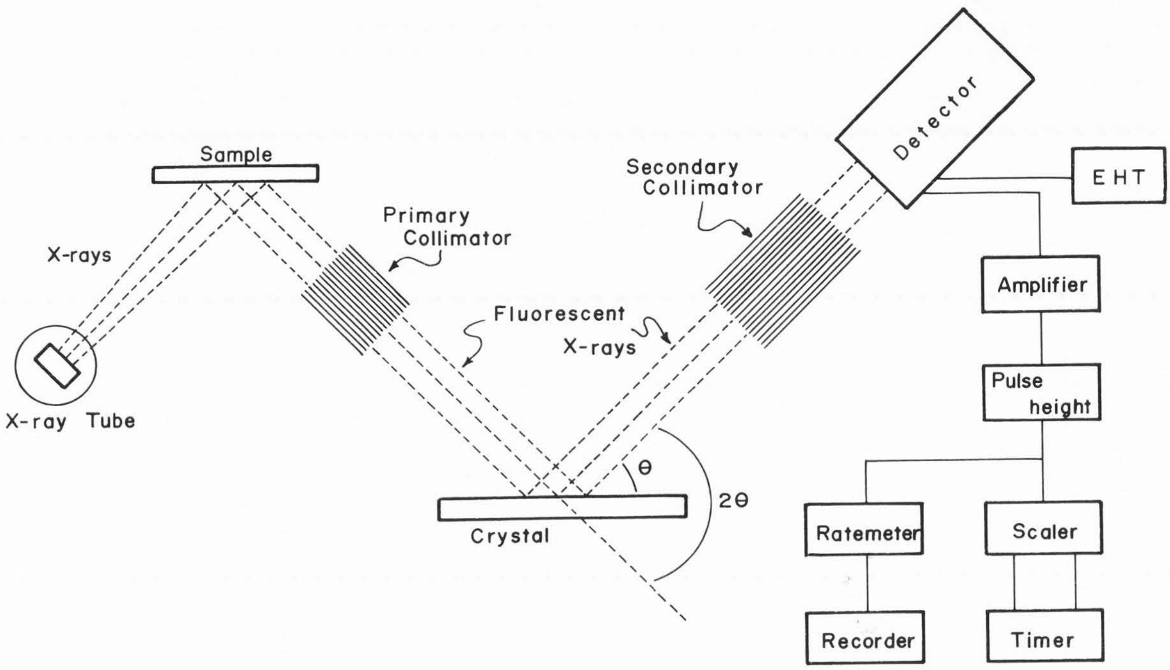

Figure 2. Schematic diagram of the X-ray fluorescence instrument showing the two theta angle (EHT represents the detector voltage) (after Norrish and Chappell 1977).

three groups: 1) rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), and manganese oxide (MnO); 2) ferric oxide (Fe_2O_3), titanium oxide (TiO_2), and barium (Ba); and 3) sodium oxide (Na_2O).

Measured intensities were corrected for counter deadtime, background, instrumental drift, and where necessary, spectral overlap (Norrish and Chappell 1977; Hutchison 1974). The corrected net peak data were then interpreted using two computational procedures: 1) a linear calibration of concentration to net peak intensity was used for Na_2O, TiO_2, MnO, Fe_2O_3, and Ba and 2) a linear calibration of concentration to the ratio of net peak intensity to the intensity of coherently scattered radiation from the tungsten (W) L_{γ_1} tube line was used for Rb, Sr, Y, Zr, and Nb (Norrish and Chappell 1977; Jenkins and DeVries 1969; Bertin 1970). The accuracy of these methods is shown in Table 2 which compares the results of analysis of nine international rock standards to the reported values of Flanagan (1973, 1976); Fabbi and Espos (1976); and Steele (1979).

The samples were prepared for analysis by crushing about 0.5 grams of obsidian in a Plattner's alloy tool steel percussion mortar and pestle to minus 40 mesh and then pulverizing the resultant chips in an agate vial using a Spex 5100 mixer/mill. The chips were ground for 15 minutes to a powder of approximately 400 mesh. Pellets were made by pressing 0.500 grams of obsidian powder under a pressure of 1,170 kg. per cm^2 using a Fabbi-type die (Fabbi 1970) and a Spex B-25 hydraulic press. Whatman CF-11 cellulose powder was used for the backing and shoulders of the pellet.

Table 2. Comparison of the results of X-ray fluorescence analysis of international geologic standards to their reported values.

Geological Source	Source of Data	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
G-2	XRF	170	480	9	301	10	0.032	2.65	0.465	1865	4.08
G-2	Flanagan 1973; 1976	168	479	12	300	14	0.034	2.65	0.50	1870	4.07
GSP-1	XRF	253	233	26	532	19	0.037	4.03	0.615	1249	2.82
GSP-1	Flanagan 1973; 1976	254	233	30	500	29	0.042	4.33	0.66	1300	2.80
AGV-1	XRF	69	655	10	182	4	0.097	6.80	1.044	1207	3.95
AGV-1	Flanagan 1973; 1976	67	657	21	255	15	0.097	6.76	1.04	1208	4.26
GA	XRF	172	298	20	134	13	0.092	2.72	0.436	826	3.40
GA	Flanagan 1973; 1976	175	305	18	140	13	0.09	2.83	0.38	850	3.55
GH	XRF	383	11	80	171	78	0.055	1.43	0.080	27	3.82
GH	Flanagan 1973	390	10	70	160	85	0.05	1.34	0.08	22	3.85
NIM-G	XRF	322	12	140	303	51	0.021	2.13	0.090	118	3.43
NIM-G	Steele 1979	325	10	147	300	53	0.021	2.00	0.090	120	3.36
GM	XRF	261	132	34	170	29	0.049	1.94	0.201	334	3.87
GM	Flanagan 1973	250	133	26	145	17	0.04	2.02	0.21	328	3.76
RGM-1	XRF	155	107	28	248	16	0.041	2.02	0.287	833	3.92
RGM-1	Fabbi & Espos 1976	154	117	--	212	--	0.037	1.95	0.193	827	3.92
QLO-1	XRF	76	338	26	178	11	0.095	4.59	0.647	1375	4.15
QLO-1	Fabbi & Espos 1976	68	329	--	175	--	0.097	4.42	0.635	1392	4.07

Correlation of Artifacts to Sources

Graphical and statistical methods were used to correlate the artifacts to the obsidian sources. The graphics involved comparing the relative concentrations of three elements and plotting the results on a three coordinate (ternary) graph. This study used the following element combinations: Rb, Sr, Zr; $Fe_2O_3/10$, TiO_2, MnO; and Ba, TiO_2, MnO. Once the range of variation for the sources was determined and plotted, the artifacts and the sources were correlated by plotting the artifacts to determine if they fell within the range of variation for a source. A computer program written by the author and utilizing a software package entitled Plot 79, Release 1.5 (Beebe 1980), was developed to do the graphics. Figure 3 illustrates the graphs produced by this method and shows the range of variation for the geologic sources of obsidian analyzed and used for this report.

The statistical validity of graphically correlating the Cerros and Yaxchilan obsidian artifacts to the geologic sources was tested by the statistical procedure of discriminant analysis using the $SPSS^x$ subprogram DISCRIMINANT (SPSS Inc. 1983). Discriminant analysis combines the discriminating variables in a stepwise fashion in such a manner that the variables are used in the order of their highest value as discriminating functions. In this way the groups are forced to be as statistically distinct as possible.

The minimum Wilk's Lambda was used for controlling the stepwise selection of discriminant functions. Because the magnitude of variation between the values reported for the different elements is large, a logarithmic (base 10) transformation was used to normalize the values. Table 3 shows that for this project, barium was the single best discriminating variable and that the next best discriminating variable in combination with barium was manganese, then iron, etc. The relative discriminating power of these elements is not constant and will depend upon their relative concentrations and variations within a given suite of samples (Nelson et al. 1978; Nelson and Holmes 1979). Table 4 gives the results of analysis of three obsidian sources in Guatemala -- two of these appear to have been used by prehistoric peoples at Cerros and Yaxchilan.

Table 3. Results of the stepwise selection of the discriminating functions and their relative value in classifying the obsidian samples into groups.

Discriminating Function	Eigenvalue	Percent Variance	Wilk's Lambda	Chi-square
Ba	853.42538	46.27	0.0000000	3233.5
MnO	629.50837	34.13	0.0000000	2514.6
Fe_2O_3	180.79294	9.80	0.0000000	1828.0
TiO_2	133.35778	7.23	0.0000064	1273.9
Zr	33.05317	1.79	0.0008576	752.04
Sr	12.76940	0.69	0.0292043	376.31
Rb	1.48678	0.08	0.4021258	97.020
Na_2O	--------	----	---------	------

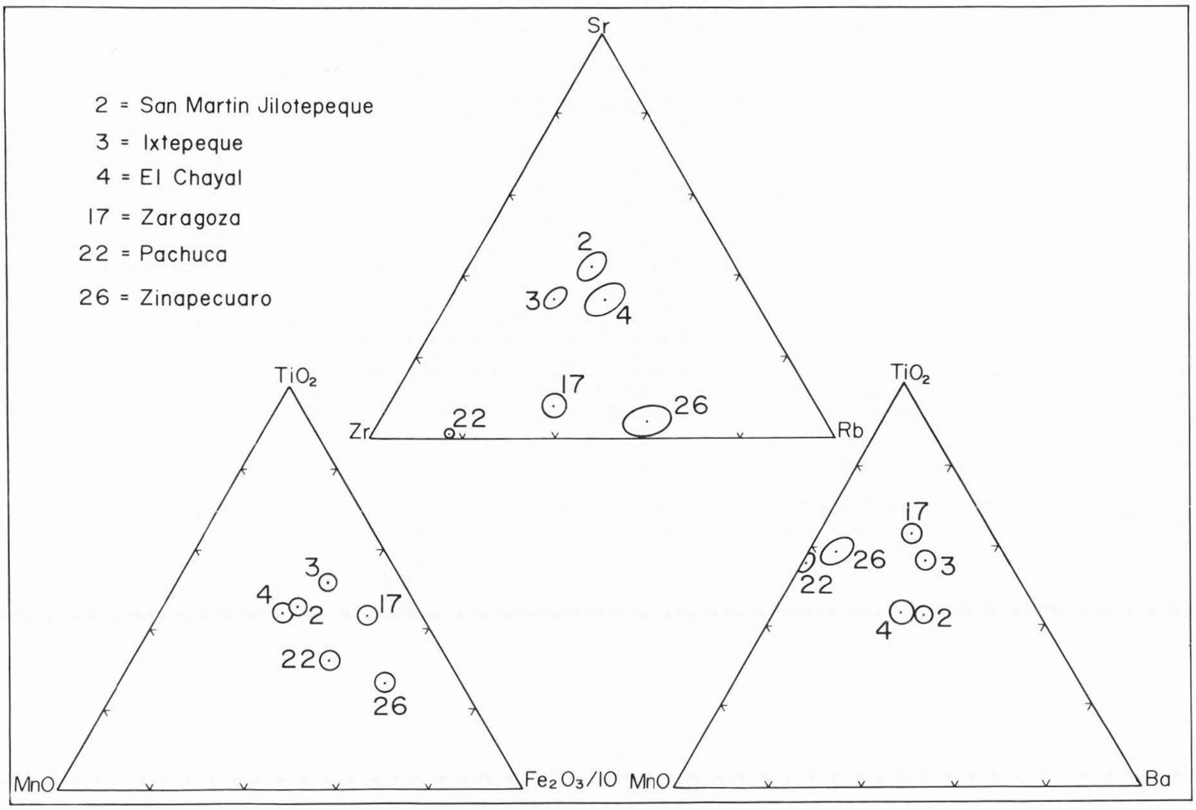

Figure 3. Graphical representation of the relative concentrations of Rb, Sr, Zr; $Fe_2O_3/10$, TiO_2, MnO; and Ba, TiO_2, MnO of selected geologic sources of obsidian from Mesoamerica. The circles and ellipses show the range of values of the obsidian sources.

Table 4. The results of analysis of geologic samples of obsidian from the sources from which the obsidian artifacts appear to have come.

		Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
				Source 2. San Martin Jilotepeque, Guatemala							
n=8	Ave.	114	182	31	137	25	0.079	0.92	0.145	1092	3.78
	S.D.	1.6	3.6	7.8	9.4	14	0.001	0.03	0.004	12.4	0.06
				Source 3. Ixtepeque, Guatemala							
n=6	Ave.	100	152	30	186	22	0.068	1.42	0.223	1041	3.88
	S.D.	1.9	2.5	4.0	6.6	3.3	0.0005	0.01	0.002	10.5	0.04
				Source 4. El Chayal, Guatemala							
n=18	Ave.	148	150	35	139	24	0.096	0.88	0.144	934	4.09
	S.D.	3.0	3.3	6.2	12	5.1	0.002	0.01	0.002	7.3	0.04

In addition to constructing discriminant functions for samples of known provenience, the SPSS^X subprogram DISCRIMINANT can be used to classify unknown samples and to calculate the probability that a given sample belongs to a given source. The program then reports the second most probable group to which a sample may be assigned (Nelson 1984; Nelson and Holmes 1979). Once the geologic obsidian sources had been grouped and the groups verified, then the Cerros and Yaxchilan obsidian artifacts could be added to the program. They were then individually assigned to the geologic source from which they probably came. Tables 5 and 6 report the trace element composition of each of the obsidian artifacts and the apparent geologic obsidian source. Figure 4 illustrates the correspondence between the artifacts and the sources.

Cerros, Belize Obsidian Artifacts

"The site of Cerros is located directly on the coast of Chetumal Bay` opposite Corozal Town, Belize" (Freidel 1978). Its location on the coast in northern Belize (Figure 1) has led some to postulate the importance of Cerros as a trade or redistribution center and it was hoped that the analysis of these obsidian artifacts would help clarify this.

Of the 10 obsidian artifacts from Cerros, Belize reported herein, five date to Late Preclassic times, two to Early Classic times and three to Late Postclassic times (Table 5). All five of the artifacts dating to Late Preclassic times appear to be made of El Chayal obsidian. These artifacts came from the dispersed settlement area of the site and date to the latter part of this period. The two Early Classic artifacts appear to be made of obsidian from El Chayal (1 artifact) and Ixtepeque (1 artifact). Of the three Late Postclassic obsidian artifacts, one appears to be made of El Chayal obsidian and two appear to be made of Ixtepeque obsidian. Also, eleven obsidian artifacts from Cerros dating to an early phase of the Late Preclassic period have been analyzed at the Lawrence Berkeley Laboratory, University of California, Berkeley, California. All of these appear to be made of obsidian from the El Chayal obsidian source (S. Lewenstein 1981, personal communication; B. Mitchum 1981, personal communication). These eleven artifacts came from a coastal midden at Cerros. Table 7 summarizes the results of analyses reported in Table 5 for this study and those conducted at the Lawrence Berkeley Laboratory.

Yaxchilan, Chiapas, Mexico Obsidian Artifacts

Yaxchilan is a very important and well known Classic Maya archaeological site located on the Usumacinta River (which is the border between Mexico and Guatemala at this point) in Chiapas, Mexico (Figure 1). It has been famous for many years because of the hieroglyphic inscriptions and the prehistoric architecture found there. However, only in the last few years have archaeological excavations been conducted at Yaxchilan. The analysis by X-ray fluorescence of 12 obsidian artifacts from this site are reported herein.

The obsidian artifacts from Yaxchilan probably date to Late Classic times (A.D. 600 -

Table 5. Results of analysis of obsidian artifacts from Cerros, Belize.

Sample Number	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %	Obsidian Source
				Late Preclassic Period					
1013	144	155	136	0.092	0.92	0.146	928	4.13	El Chayal
1014	137	158	136	0.092	0.92	0.146	932	4.21	El Chayal
1015	151	156	142	0.093	0.86	0.148	939	4.17	El Chayal
1016	141	149	136	0.093	0.87	0.147	934	4.19	El Chayal
1017	142	151	142	0.093	0.94	0.147	935	4.18	El Chayal
				Early Classic Period					
1018	144	154	134	0.092	0.87	0.144	924	4.09	El Chayal
1019	95	152	190	0.066	1.47	0.233	1034	3.93	Ixtepeque
				Late Postclassic Period					
1020	135	147	142	0.092	0.88	0.147	946	4.21	El Chayal
1021	98	155	183	0.066	1.47	0.233	1042	3.90	Ixtepeque
1022	94	151	185	0.065	1.46	0.235	1047	3.89	Ixtepeque

Table 6. Results of analysis of Late Classic obsidian artifacts from Yaxchilan, Chiapas, Mexico.

Sample Number	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %	Obsidian Source
804	151	160	129	0.095	0.85	0.147	937	4.23	El Chayal
805	100	151	200	0.068	1.45	0.224	1030	3.90	Ixtepeque
806	99	154	175	0.069	1.46	0.222	1051	3.36	Ixtepeque
807	151	155	132	0.094	0.85	0.144	923	4.16	El Chayal
808	149	152	118	0.094	0.84	0.145	929	4.17	El Chayal
809	151	153	152	0.094	0.83	0.145	932	4.22	El Chayal
810	149	134	152	0.096	0.84	0.148	939	4.31	El Chayal
811	146	139	144	0.095	0.82	0.145	933	4.21	El Chayal
812	146	149	130	0.095	0.83	0.145	925	4.20	El Chayal
813	140	149	145	0.096	0.83	0.147	939	4.25	El Chayal
814	147	153	145	0.095	0.83	0.149	951	4.32	El Chayal
815	147	143	139	0.095	0.84	0.146	936	4.24	El Chayal

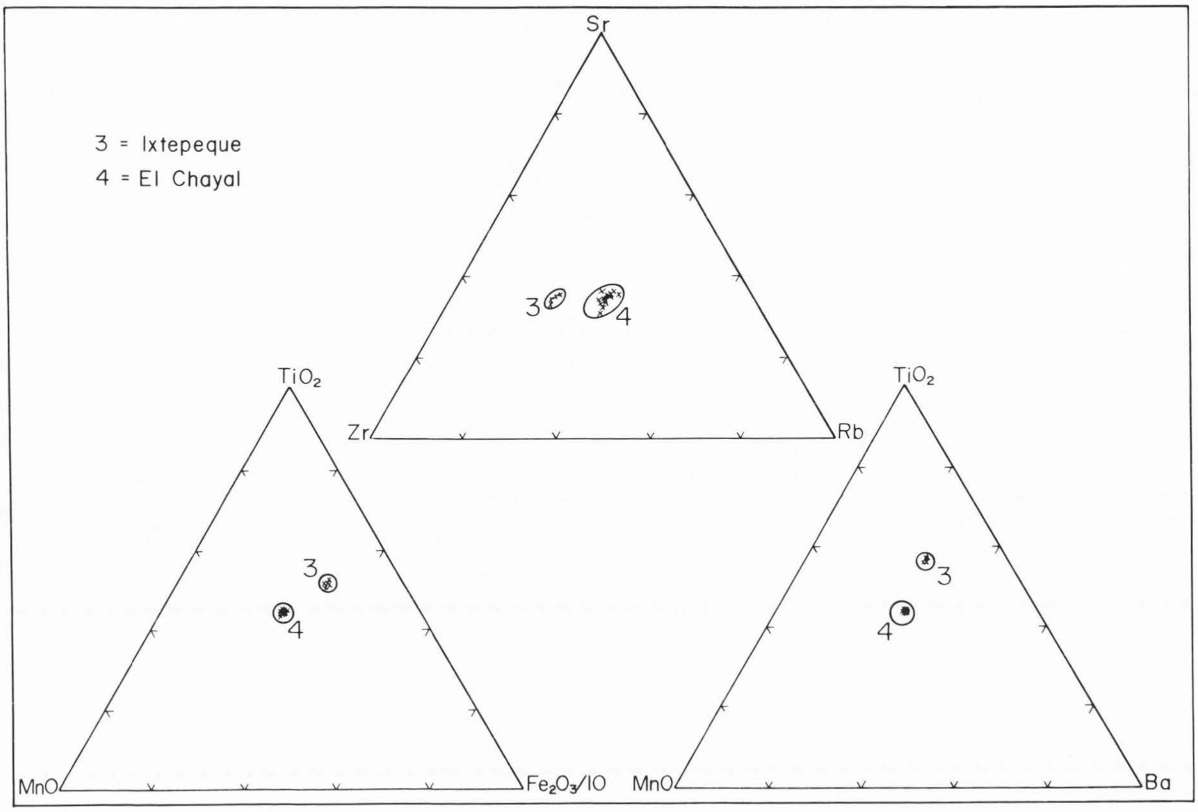

Figure 4. Graphical representation of the relative concentrations of Rb, Sr, Zr; $Fe_2O_3/10$, TiO_2, MnO; and Ba, TiO_2, MnO of the obsidian artifacts from Cerros and Yaxchilan and of the geologic sources of obsidian to which they correspond. The "X's" represent the artifacts and the circles and ellipses show the range of values of the obsidian sources.

800). As can be seen in Table 6 the obsidian for 10 of the artifacts appears to have come from the El Chayal obsidian source and the other 2 artifacts appear to be made of obsidian from the Ixtepeque obsidian source. The obsidian probably arrived at Yaxchilan via the Usumacinta River. Yaxchilan is a very prominent site along the river and was probably an important trade center during the Late Classic Period. Its location would have allowed its inhabitants to control traffic along the river.

Discussion

The results of analysis by X-ray fluorescence of the ten obsidian artifacts from Cerros and the twelve artifacts from Yaxchilan have been presented (see Tables 5 and 6). These data and data obtained at the Lawrence Berkeley Laboratory indicate that El Chayal was the principal obsidian source during Late Preclassic and Classic times and that Ixtepeque became important during Postclassic times. These results are similar to those reported by others from several archaeological sites in the Lowland Maya area. The data from other archaeological sites will be summarized by archaeological period and compared to the results of analysis from Cerros and Yaxchilan.

Table 7. Summary of obsidian analyses from Cerros, Belize.

Late Preclassic (400 B.C. - A.D. 250)		
El Chayal	16 Artifacts	100%
Early Classic (A.D. 250 - 600)		
El Chayal	1 Artifact	50%
Ixtepeque	1 Artifact	50%
Late Postclassic (A.D. 1250 - 1550)		
El Chayal	1 Artifact	33%
Ixtepeque	2 Artifacts	67%

Middle Preclassic Period (1000 - 400 B.C.). At the present time there is little or no evidence that either Cerros or Yaxchilan were occupied during this time period. However, other sites in the Maya Lowlands were inhabited and obsidian from these sites has been analyzed. During Middle Preclassic times almost all of the analyzed obsidian artifacts found at Maya Lowland archaeological sites appear to have come from San Martin Jilotepeque (also called Rio Pixcaya, see Stross et al. 1983) in highland Guatemala (Table 8). The only exceptions up to the present time are Seibal, Peten (Nelson et al. 1978) which

Table 8. Results of analysis of Middle Preclassic (1000 - 400 B.C.) obsidian artifacts from the Maya Lowlands as reported in the literature.

J. DZIBILNOCAC, CAMPECHE, MEXICO		n = 1
#2 San Martin Jilotepeque	100%	Nelson et al. (1977)
K. EDZNA, CAMPECHE, MEXICO		n = 12
#2 San Martin Jilotepeque	100%	Nelson et al. (1983)
S. TIKAL, PETEN, GUATEMALA		n = 1
#2 San Martin Jilotepeque	100%	Nelson et al. (1977)
T. CENTRAL PETEN LAKES, PETEN, GUATEMALA		n=63
#2 San Martin Jilotepeque	75%	
#4 El Chayal	18%	Rice (1984)
#3 Ixtepeque	5%	
#1 Tajumulco	1%	
V. SEIBAL, PETEN, GUATEMALA		n = 27
#2 San Martin Jilotepeque	93%	Nelson et al. (1978)
#4 El Chayal	7%	

Table 9. Results of analyses of Late Preclassic (400 B.C. - A.D. 250) obsidian artifacts from the Maya Lowlands as reported in the literature.

K. EDZNA, CAMPECHE, MEXICO		n = 41
#2 San Martin Jilotepeque	27%	
#4 El Chayal	68%	Nelson et al. (1983)
#3 Ixtepeque	5%	
L. BECAN, CAMPECHE, MEXICO		n = 13
#2 San Martin Jilotepeque	23%	
#4 El Chayal	62%	Rovner (1981)
#3 Ixtepeque	15%	
S. TIKAL, PETEN, GUATEMALA		n = 43
#2 San Martin Jilotepeque	47%	
#4 El Chayal	21%	Moholy-Nagy (1975)
#3 Ixtepeque	23%	Moholy-Nagy et al.
#12 Media Cuesta	5%	(1984)
#22 Pachuca	5%	
CERROS, BELIZE		n = 16
#4 El Chayal	100%	This Report
NORTHERN BELIZE		n = 2
#4 El Chayal	100%	Neivens et al. (1983)
N. NOHMUL, BELIZE		n = 1
#4 El Chayal	100%	Hammond et al. (1984)
O. COLHA, BELIZE		n = 5
#2 San Martin Jilotepeque	20%	Hester & Michel (1980)
#4 El Chayal	80%	Hester & Shafer (1983)
P. BARTON RAMIE, BELIZE		n = 1
#2 San Martin Jilotepeque	100%	Nelson et al. (1978)
W. PALENQUE, CHIAPAS, MEXICO		n = 2
#4 El Chayal	100%	Johnson (1976a)
V. SEIBAL, PETEN, GUATEMALA		n = 21
#2 San Martin Jilotepeque	90%	Nelson et al. (1978)
#4 El Chayal	10%	

received 93% of its obsidian from San Martin Jilotepeque and 7% from El Chayal and the Central Peten Lakes (Rice 1984) which received 75% from San Martin Jilotepeque, 18% from El Chayal, 5% from Ixtepeque, and 1% from Tajumulco (Table 8). It is curious that San Martin Jilotepeque should have been the dominant obsidian source for the Lowland Maya during the Middle Preclassic period --- especially when El Chayal is the most important obsidian source for the Late Preclassic and Classic periods. It is possible that the almost exclusive use of San Martin Jilotepeque obsidian during the Middle Preclassic period by the Lowland Maya may have been because of the monopoly on El Chayal obsidian held by the Early and Middle Preclassic cultures of coastal Chiapas, eastern Oaxaca, and the Olmec of southern Veracruz. The change from the San Martin Jilotepeque obsidian source to the El Chayal obsidian source is seen as the result of the decline of the Olmec culture at San Lorenzo by the beginning of Middle Preclassic times and the cultures of eastern Oaxaca by the end of Middle Preclassic times. Zeitlin (1978) sees this change of obsidian sources during Late Preclassic times at Laguna Zope and has suggested that it may be the result of intensifying political and economic relations with the north (Valley of Mexico) and because El Chayal obsidian was being taken into the Maya area.

The route over which San Martin Jilotepeque obsidian was carried north appears to have followed the natural land and river routes as it moved from site to site in the central Peten area (Figure 5). This route may have included Coban, the Pasion River to Seibal and then overland to the Central Peten Lakes, Tikal, and then to Edzna, and Dzibilnocac. Also, during this time El Chayal was still an important obsidian source in the southern Isthmus of Tehuantepec area and San Martin Jilotepeque obsidian was being taken through the Central Depression of Chiapas and on to La Venta (Figure 5).

Late Preclassic Period (400 B.C. - A.D. 250).

The Late Preclassic period includes both the Late Preclassic and Protoclassic periods since, up to the present time, the obsidian data have not been reported in such a way that a distinction can be made. As can be seen in Table 9, El Chayal became much more important as an obsidian source during Late Preclassic time and remained so until Postclassic times. However, San Martin Jilotepeque obsidian was still being used in the Maya area in significant quantities during Late Preclassic times. Also, Ixtepeque obsidian was being taken into the central area to Tikal, Becan

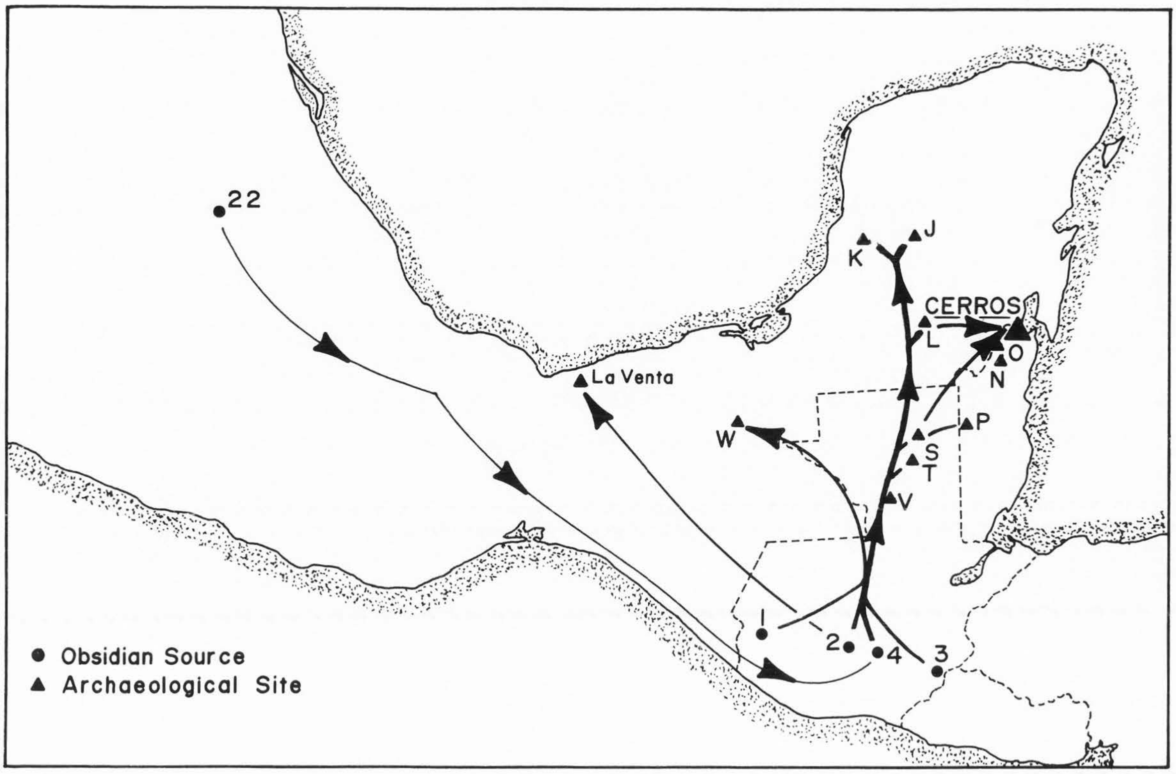

Figure 5. Possible routes of exchange during Middle and Late Preclassic times according to the obsidian data. The letters represent the archaeological sites and the numbers represent the geologic sources of obsidian (see Tables 8 and 9 for the identification of the sources and sites).

and the Central Peten Lakes with smaller amounts appearing in northern Yucatan at Edzna.

In the northern area of the Lowland Maya region at Edzna (Nelson et al. 1983) and Becan (Rovner 1981), El Chayal was the most important obsidian source. In the more southern part of the area, at Seibal (Nelson et al. 1978), Tikal (Moholy-Nagy 1975; Moholy-Nagy et al. 1984), and the Central Peten Lakes (Rice 1984); San Martin Jilotepeque obsidian was still being used in larger amounts than El Chayal obsidian. At Palenque, Chiapas (Johnson 1976a, 1976b) 100% of the obsidian analyzed from Late Preclassic deposits came from El Chayal. The only evidence for Mexican obsidian in the Maya area during Late Preclassic times is at Tikal where 5% of the analyzed obsidian came from Pachuca, Hidalgo (Moholy-Nagy 1975).

It appears that the Late Preclassic period in the Maya Lowlands was a transition period in which the major source of obsidian was changing from San Martin Jilotepeque to El Chayal. The obsidian data from the Middle Preclassic period and the Early Classic period support this. It appears that most of the analyzed obsidian used during Middle Preclassic times came from San Martin Jilotepeque, that obsidian from both San Martin Jilotepeque and El Chayal was used during Late Preclassic times, and that during Early Classic times most of the Guatemalan obsidian came from El Chayal (Tables 8, 9 and 10).

The change of obsidian sources is an indication that the routes over which it was carried also probably changed. However, during Late Preclassic times this change probably did not have much effect on the overland trade routes because the distance from San Martin Jilotepeque to El Chayal is small in comparison to the distance from the Highlands to the Lowlands. However, it is an indication that less and less El Chayal obsidian was being taken along the Pacific Coast. At about this time Kaminaljuyu probably began to control the El Chayal obsidian source and therefore began to negotiate trade relations with the Lowland Maya instead of the cultures in the Isthmus of Tehuantepec region.

It appears that San Martin Jilotepeque and El Chayal obsidian probably followed the Middle Preclassic overland and riverine routes to Coban, Sebol, the Pasion River, Seibal and overland to Tikal and then on north to Becan, and Edzna (Figure 5). The sites in northern Belize such as Cerros, Nohmul, Colha and Barton Ramie also probably received obsidian via this overland route from Tikal (Hammond et al. 1984) and/or El Mirador. The majority of obsidian appears to have arrived in the Lowlands via the overland routes that began during Middle Preclassic times and continued to exist and to be used. Also, Ixtepeque obsidian; which does not appear in the southern Maya Lowlands at Seibal or in northern Belize during this time; has been found at Tikal, the Central Peten Lakes, and in Campeche at Becan and Edzna (Table 9) and may have moved along this same overland route.

Freidel (1978, 1979) and Andrews (1981) have suggested that long distance canoe trade was important to the Late Preclassic florescence of Cerros in northern Belize and possibly at other sites as well. Freidel has described Cerros as a transhipment point from which commodities were taken into the interior and has also suggested that the coastal route may have extended north to the Dzibilchaltun area.

It is true that commodities, such as shells, that originated in coastal areas probably were taken to sites such as Tikal, the northern Peten Lakes, and El Mirador. Obsidian was probably one item exchanged for these commodities and therefore would have arrived at Cerros from these inland redistribution centers and probably not via the coastal routes.

Early Classic Period (A.D. 250 - 600).

The transition from San Martin Jilotepeque to El Chayal obsidian appears to be complete by Early Classic times (Table 10). During this period almost all of the Guatemalan obsidian found at archaeological sites in the Lowland Maya area came from El Chayal with only small amounts coming from Ixtepeque (at Becan, Cerros, Northern Belize, and Moho Cay) and San Martin Jilotepeque (at Becan, Tikal, Central Peten Lakes, and Seibal) (Table 10). The other important source of obsidian in the Maya area during this time was green obsidian from Pachuca, Hidalgo, Mexico. Edzna, Becan, and Tikal all received significant amounts of green obsidian from this source. It is interesting that no green obsidian has been found at Seibal (Willey 1978; Nelson et al. 1978) or at Palenque (Johnson 1976a) during this period. However, Pachuca obsidian was found at Yoxiha in the vicinity of Palenque (Johnson 1976a). The green obsidian in the Maya area is evidence for Teotihuacan influence in the Lowlands during the Early Classic period. Archaeologists have known about the Mexican influence in the Lowlands for a long time from ceramic and architectural evidence as well as from the green obsidian. However, the route and mechanism by which it arrived in the Lowlands are not so well understood.

Small amounts of Mexican obsidian were also coming into the Maya Lowlands from Otumba, Paredon, Zaragoza, Ucareo, Altotonga, and Tulancingo (Table 10). It is possible that obsidian from these sources arrived along the same route as the Pachuca obsidian.

It appears that the overland and riverine routes that developed in earlier times continued to be used and probably followed the same trails and river systems as were used during Preclassic times (Figure 6). The use of the same overland trade routes through Preclassic and Classic times is reasonable because of the rugged terrain in highland Guatemala and the jungles of the lowland Maya area. Once the routes had been established it would have been much easier to use and maintain them than to construct new routes through the jungles.

Pachuca obsidian probably arrived at the Lowland Maya centers by way of Kaminaljuyu. This route may have followed the important Late Postclassic route described by Lee (1978) which began in the Valley of Mexico and went to Tuxtepec, Oaxaca. At Tuxtepec the route divided

Table 10. Results of analysis of Early Classic (A.D. 250 - 600) obsidian artifacts from the Maya Lowlands as reported in the literature.

	D. COBA, QUINTANA ROO, MEXICO		n = 3
#4	El Chayal	100%	Nelson et al. (1983)
	K. EDZNA, CAMPECHE, MEXICO		n = 9
#4	El Chayal	78%	Nelson et al. (1983)
#22	Pachuca	22%	
	L. BECAN, CAMPECHE, MEXICO		n = 93
#2	San Martin Jilotepeque	1%	
#4	El Chayal	83%	
#3	Ixtepeque	2%	Rovner (1981)
#22	Pachuca	13%	
#18	Altotonga	1%	
	M. CHICANNA, CAMPECHE, MEXICO		n = 6
#4	El Chayal	100%	Rovner (1981)
	CERROS, BELIZE		n = 2
#4	El Chayal	50%	This Report
#3	Ixtepeque	50%	
	NORTHERN BELIZE		n = 42
#4	El Chayal	86%	Neivens et al. (1983)
#3	Ixtepeque	14%	
	N. NOHMUL, BELIZE		n = 1
#4	El Chayal	100%	Hammond et al. (1984)
	Q. MOHO CAY, BELIZE		n = 13
#4	El Chayal	92%	Healy et al. (1984)
#3	Ixtepeque	8%	
	S. TIKAL, PETEN, GUATEMALA		n = 69
#2	San Martin Jilotepeque	6%	
#4	El Chayal	59%	
#22	Pachuca	22%	Moholy-Nagy (1975)
#23	Tulancingo	2%	Moholy-Nagy et al.
#16	Otumba	6%	(1984)
#25	Ucareo	3%	
	Unknown	3%	
	T. CENTRAL PETEN LAKES, PETEN, GUATEMALA		n=25
#2	San Martin Jilotepeque	24%	
#4	El Chayal	72%	Rice (1984)
#22	Pachuca	4%	
	V. SEIBAL, PETEN, GUATEMALA		n = 2
#2	San Martin Jilotepeque	50%	Nelson et al. (1978)
#4	El Chayal	50%	
	W. PALENQUE, CHIAPAS, MEXICO		n = 5
#4	El Chayal	100%	Johnson (1976a)

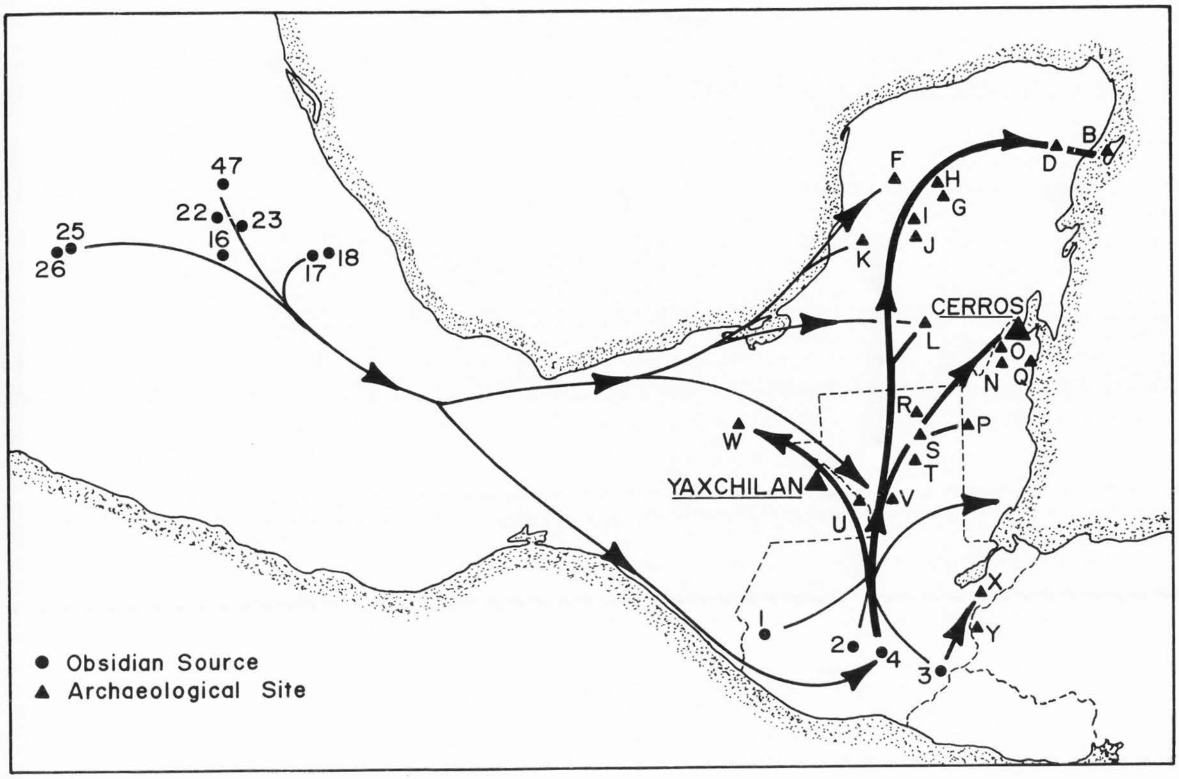

Figure 6. Possible routes of exchange during Classic times according to the obsidian data. The letters represent the archaeological sites and the numbers represent the geologic sources of obsidian (see Tables 10, 11 and 12 for the identification of the sources and sites).

and the Pachuca obsidian probably followed the route to the Pacific coast of the Isthmus of Tehuantepec and then along the coast to Soconusco, Chiapas. From the Soconusco area the route would have left the coast and followed the trails into the Guatemalan Highlands and finally to Kaminaljuyu (Figure 6). The Pacific coastal route is postulated here because it appears that strong Teotihuacan influence does not get much past Chiapa de Corzo in the Central Depression (J.E. Clark 1981, personal communication) and there is some evidence for green obsidian along the Pacific Coast (Nelson and Voorhies 1980). This is also the old Olmec obsidian route that had existed since at least Early Preclassic times. From Kaminaljuyu the Pachuca obsidian would have followed the well established obsidian routes overland down to the Lowland Maya area. Obsidian from other Mexican sources may have also followed this route.

Other authors have also suggested that the Classic period trade routes probably used the overland trails and riverine systems. Freidel (1978) and Jones (1979) emphasize the importance of land routes during this time and Sabloff (1977) has said that Coba may have been built to control trade (salt and perhaps honey) in the northeastern area of the Yucatan Peninsula. "It is likely that much of this trade was by land rather than by sea. The absence of any significant occupation on Cozumel during this time period, coupled with the lack of any large coastal Early Period sites in Quintana Roo, would also support the land hypothesis" (Sabloff 1977).

Late Classic Period (A.D. 600 - 800).

During Late Classic times most of the archaeological sites in the Maya area appear to have been quite consistent as to their source of obsidian and the percentage of obsidian from each source. El Chayal continued as the principal source of obsidian for the Lowland Maya area (Table 11). However, smaller amounts of obsidian were also coming from San Martin Jilotepeque, Ixtepeque, Tajumulco, and Media Cuesta in Guatemala (Table 11) (Figure 1). Johnson (1976a) is the first to report obsidian from Tajumulco in the Lowland Maya area during Classic times. However, it was extensively used during Archaic times at Chantuto, Chiapas (Nelson and Voorhies 1980) and during Early Preclassic times along the Chiapas Coast at sites such as Paso de la Amada (Clark and Lee 1984).

Hammond et al. (1984) have hypothesized on the basis of the large percentage of Ixtepeque obsidian at Nohmul during this period, that obsidian sources and trade routes may have begun to change. However, when the data from all the sites are taken into account it is apparent that there has only been an increase in the use of Ixtepeque obsidian from 3.5% during Early Classic times to 13.1% during Late Classic times (at Yaxchilan 17% of its analyzed obsidian came from Ixtepeque). However, until more obsidian artifacts are analyzed from Late Classic times along the Caribbean Coast the data appear to indicate that the majority of the obsidian continued to arrive in the Maya Lowlands via the central overland routes (Hammond et al. 1984).

The major difference in obsidian sources in the Maya area between the Early Classic and Late Classic periods is the change in Mexican sources of obsidian. There is less evidence for green obsidian from Pachuca, Hidalgo during Late Classic times with the possible exception of Tikal where green obsidian has been reported during Late Classic times (Moholy-Nagy et al. 1984). However, it appears that small amounts of obsidian were also coming from Tulancingo, Otumba, Zacualtipan, Ucareo, and Zinapecuaro (Table 11). The small amounts of obsidian from these Mexican sources probably did not follow the Teotihuacan - Pachuca route along the Pacific Coast but instead went from Tuxtepec, Oaxaca to Xicalango on the Gulf Coast. From Xicalango the obsidian could have been taken up the Usumacinta and Pasion Rivers or along the Gulf Coast and then inland (Figure 6).

<u>Terminal Classic (A.D. 800 - 1000).</u>

During the Terminal Classic period the principal source of obsidian used by the Lowland Maya continued to change (Table 12). El Chayal still appears to be the major source of obsidian but Ixtepeque also appears in significant quantities at most of the sites. From Table 12 it appears that the farther south and the closer to the Caribbean Coast the site is located the percentage of obsidian from Ixtepeque increases. Also, Mexican obsidian continues to be used in small amounts from Zacualtipan, Zaragoza, Altotonga, and Zinapecuaro (Table 12).

During this period the routes were probably also changing. Putun traders may have begun to

Table 11. Results of analyses of Late Classic (A.D. 600 - 800) obsidian artifacts from the Maya Lowlands as reported in the literature.

	H. LABNA, YUCATAN, MEXICO		n = 1
#4	El Chayal	100%	Nelson et al. (1977)
	G. LOLTUN CAVE, YUCATAN, MEXICO		n = 2
#4	El Chayal	50%	Nelson et al. (1977)
	D. COBA, QUINTANA ROO, MEXICO		n = 4
#4	El Chayal	100%	Nelson et al. (1983)
	B. COZUMEL, QUINTANA ROO, MEXICO		n = 2
#4	El Chayal	100%	Nelson et al. (1983)
	I. SANTA ROSA XTAMPAK, CAMPECHE, MEXICO		n = 2
#4	El Chayal	100%	Nelson et al. (1977)
	J. DZIBILNOCAC, CAMPECHE, MEXICO		n = 6
#4	El Chayal	67%	
#12	Media Cuesta	17%	Nelson et al. (1977)
	Unknown	17%	
	K. EDZNA, CAMPECHE, MEXICO		n = 8
#2	San Martin Jilotepeque	13%	
#4	El Chayal	62%	Nelson et al. (1983)
#26	Zinapecuaro	25%	

Table 11. Continued.

	L. BECAN, CAMPECHE, MEXICO		n = 30
#4	El Chayal	87%	Rovner (1981)
#3	Ixtepeque	13%	
	M. CHICANNA, CAMPECHE, MEXICO		n = 2
#4	El Chayal	100%	Rovner (1981)
	N. NOHMUL, BELIZE		n = 27
#4	El Chayal	30%	Hammond et al. (1984)
#3	Ixtepeque	70%	
	O. COLHA, BELIZE		n = 1
#4	El Chayal	100%	Hester & Michel (1980)
			Hester & Shafer (1983)
	P. BARTON RAMIE, BELIZE		n = 6
#4	El Chayal	100%	Nelson et al. (1978)
	R. UAXACTUN, PETEN, GUATEMALA		n = 3
#4	El Chayal	100%	Nelson et al. (1977)
	S. TIKAL, PETEN, GUATEMALA		n = 61
#2	San Martin Jilotepeque	2%	
#4	El Chayal	82%	
#3	Ixtepeque	5%	Moholy-Nagy (1975)
#22	Pachuca	3%	Moholy-Nagy et al.
#16	Otumba	5%	(1984)
#17	Zaragoza	3%	
	T. CENTRAL PETEN LAKES, PETEN, GUATEMALA		n=56
#2	San Martin Jilotepeque	23%	
#4	El Chayal	73%	Rice (1984)
#23	Tulancingo	4%	
	W. PALENQUE, CHIAPAS, MEXICO		n = 106
#2	San Martin Jilotepeque	1%	
#4	El Chayal	96%	Johnson (1976a)
#3	Ixtepeque	2%	
#1	Tajumulco	1%	
	YAXCHILAN, CHIAPAS, MEXICO		n = 12
#4	El Chayal	83%	This Report
#3	Ixtepeque	17%	
	V. SEIBAL, PETEN, GUATEMALA		n = 8
#4	El Chayal	75%	
#3	Ixtepeque	13%	Nelson et al. (1978)
	Unknown	12%	
	U. ALTAR DE SACRIFICIOS, PETEN, GUATEMALA		n=8
#4	El Chayal	100%	Nelson et al. (1978)
	X. QUIRIGUA, GUATEMALA		n = 30
#4	El Chayal	17%	
#3	Ixtepeque	80%	Stross et al. (1983)
	Unknown	3%	
	Y. COPAN, HONDURAS		n = 3
#4	El Chayal	100%	Nelson et al (1977)
	Z. LABAANTUN, BELIZE		n = 22
#4	El Chayal	95%	Hammond (1976)
#25	Ucareo	5%	

Table 12. Results of analysis of Terminal Classic (A.D. 800 - 1000) obsidian from the Maya Lowlands as reported in the literature.

	D. COBA, QUINTANA ROO, MEXICO		n = 4
#4	El Chayal	100%	Nelson et al. (1983)
	F. UXMAL, YUCATAN, MEXICO		n = 10
#4	El Chayal	90%	Nelson et al. (1983)
#47	Zacualtipan	10%	
	L. BECAN, CAMPECHE, MEXICO		n = 49
#4	El Chayal	71%	
#3	Ixtepeque	10%	Rovner (1981)
#17	Zaragoza	14%	
#18	Altotonga	4%	
	M. CHICANNA, CAMPECHE, MEXICO		n = 37
#4	El Chayal	73%	
#3	Ixtepeque	22%	Rovner (1981)
#17	Zaragoza	3%	
#26	Zinapecuaro	3%	
	NORTHERN BELIZE		n = 28
#4	El Chayal	93%	Neivens et al. (1983)
#3	Ixtepeque	7%	
	N. NOHMUL, BELIZE		n = 20
#4	El Chayal	20%	Hammond et al. (1984)
#3	Ixtepeque	80%	
	S. TIKAL, PETEN, GUATEMALA		n = 7
#2	San Martin Jilotepeque	57%	Moholy-Nagy (1975)
#4	El Chayal	14%	Moholy-Nagy et al.
#3	Ixtepeque	29%	(1984)
	T. CENTRAL PETEN LAKES, PETEN, GUATEMALA		n=20
#2	San Martin Jilotepeque	5%	
#4	El Chayal	65%	Rice (1984)
#3	Ixtepeque	20%	
	Unknown	10%	
	V. SEIBAL, PETEN, GUATEMALA		n = 22
#2	San Martin Jilotepeque	32%	
#4	El Chayal	50%	Nelson et al. (1978)
#3	Ixtepeque	14%	
#17	Zaragoza	5%	

use the coastal routes which may have extended around the Yucatan Peninsula to Cozumel and Lubaantun (Figure 6). However, the old land routes through the central Peten and peninsula region were probably still in use as seen in the high percentage of El Chayal obsidian that was still being brought into the Lowlands. It was during this period of Maya history that the Putun Maya began to exert strong influences in northern Yucatan at the Puuc sites and at Chichen Itza (Thompson 1970). Also at this time the population at Cozumel greatly increased (Sabloff 1977). It appears that even though a transition was taking place in the sources of obsidian and the routes used -- the central Peten and peninsula overland routes were still being used extensively.

Early Postclassic Period (A.D. 1000 - 1250).

The transition from El Chayal obsidian to Ixtepeque obsidian appears to have been almost completed during this period (Table 13). Many of the sites located in interior had been abandoned and Ixtepeque appears to have become the principal obsidian source for sites along the Caribbean Coast. Also, Mexican obsidian continues to be present from the Pachuca, Otumba, Ucareo, and Zinapecuaro sources (Table 13). The major trade routes were probably following the coast around the Yucatan Peninsula (Figure 7). This is seen both in the increased use of Ixtepeque obsidian and the decrease in El Chayal obsidian but also by the fact that few sites appear to have been occupied in the central Maya Lowlands during this period.

Table 13. Results of analysis of Early Postclassic (A.D. 1000 - 1250) obsidian artifacts from the Maya Lowlands as reported in the literature.

	E. CHICHEN ITZA, YUCATAN, MEXICO		n = 4
#22	Pachuca	50%	
#16	Otumba	25%	Nelson et al. (1977)
#26	Zinapecuaro	25%	
	B. COZUMEL, QUINTANA ROO, MEXICO		n = 6
#4	El Chayal	17%	
#3	Ixtepeque	33%	Nelson et al. (1983)
#22	Pachuca	33%	
#26	Zinapecuaro	17%	
	O. COLHA, BELIZE		
#3	Ixtepeque	100%	Hester & Michel (1980) Hester & Shafer (1983)
	T. CENTRAL PETEN LAKES, PETEN, GUATEMALA		n=26
#2	San Martin Jilotepeque	15%	
#4	El Chayal	19%	Rice (1984)
#3	Ixtepeque	58%	
	Unknown	8%	
	AA. WILD CANE CAY, BELIZE		
#4	El Chayal	17%	Hammond (1976)
#3	Ixtepeque	83%	

Late Postclassic Period (A.D. 1250 - 1550).

By Late Postclassic times it appears that almost all of the obsidian was coming from the Ixtepeque source (Table 14). Analyses of obsidian artifacts from Cozumel, Tulum, and Cancun on the northern Caribbean Coast and Cerros and northern Belize farther south support this. Therefore, the Late Postclassic obsidian data support the ethnohistoric accounts of the importance of coastal trade routes at the time of and just before the arrival of the Spaniards (Figure 7). Also, the canoe travel observed by Columbus (see Thompson 1970), the evidence for the trading ventures of the Putun Maya (Thompson 1970), and the important coastal trading centers such as Xicalango, Cozumel, and Nito are all indications of circum-peninsula trade. Also, small amounts of obsidian appear to have come from Pachuca and Pico de Orizaba (Table 14.)

The Ixtepeque obsidian was probably taken down the Motagua River and then up the Caribbean coast to Tulum, Cozumel, and Cancun and then around the Yucatan Peninsula to the Xicalango area (Figure 7). The small amount of Mexican obsidian (Table 14) coming into the Maya area would have been taken around the Peninsula in the opposite direction (Figure 7).

Thus the obsidian data indicate that between the Middle Preclassic and Late Postclassic periods at least three obsidian sources were of major importance to the Lowland Maya peoples. Also, during these time periods various other Guatemalan and Mexican obsidian sources were used at one time or another (Table 15). It appears that during Middle Preclassic times San Martin Jilotepeque was the major obsidian source of the Lowland Maya. The data indicate that the Late Preclassic period was a time of transition from the San Martin Jilotepeque obsidian source to El Chayal and that during the Classic periods El Chayal was the principal source of obsidian. The Terminal Classic period was again a transition period -- but this time it was from the El Chayal to Ixtepeque obsidian source. During Early and Late Postclassic times Ixtepeque was the principal source of obsidian. Therefore, the obsidian data indicate that long distance trade was taking place throughout the Lowland Maya area from at

Table 14. Results of analysis of Late Postclassic (A.D. 1250 - 1550) obsidian artifacts from the Maya Lowlands as reported in the literature.

	A. CANCUN, QUINTANA ROO, MEXICO			n = 4
#3	Ixtepeque	100%	Nelson et al. (1983)	
	B. COZUMEL, QUINTANA ROO, MEXICO			n = 21
#4	El Chayal	5%		
#3	Ixtepeque	90%	Nelson et al. (1983)	
#22	Pachuca	5%		
	C. TULUM, QUINTANA ROO, MEXICO			n = 10
#3	Ixtepeque	100%	Nelson et al. (1983)	
	CERROS, BELIZE			n = 3
#4	El Chayal	33%	This Report	
#3	Ixtepeque	67%		
	NORTHERN BELIZE			n = 75
#2	San Martin Jilotepeque	1%		
#4	El Chayal	18%		
#3	Ixtepeque	75%	Neivens et al. (1983)	
#22	Pachuca	4%		
#20	Pico de Orizaba	1%		
	Unknown	1%		

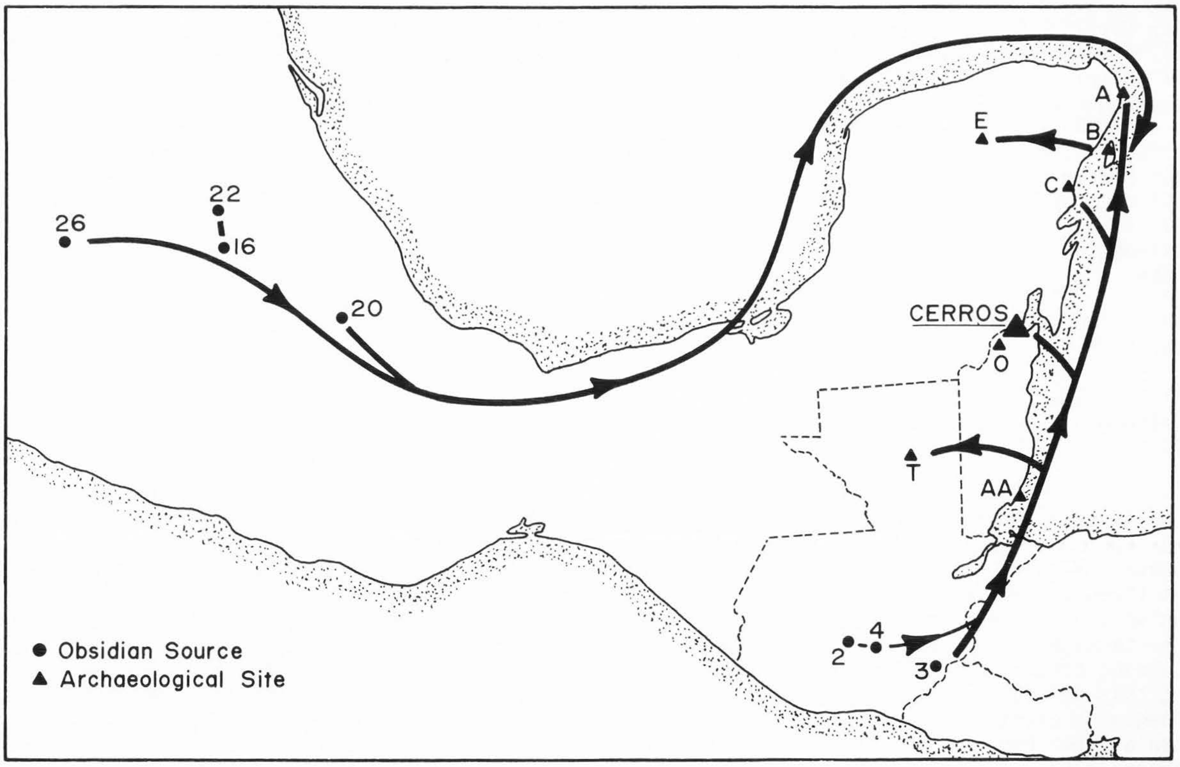

Figure 7. Possible routes of exchange during Postclassic times according to the obsidian data. The letters represent the archaeological sites and the numbers represent the archaeological sites and the numbers represent the geologic sources of obsidian (see Tables 13 and 14 for the identification of the sources and sites).

Table 15. The percentage of analyzed obsidian from the geologic sources found in the Lowland Maya area during the different archaeological periods.

Middle Preclassic Period (1000 - 400 B.C.)

San Martin Jilotepeque	87 Artifacts	83.6%
El Chayal	13 Artifacts	12.5%
Ixtepeque	3 Artifacts	2.9%
Tajumulco	1 Artifact	1.0%
	104 Artifacts	100.0%

Late Preclassic Period (400 B.C. - A.D. 250)

San Martin Jilotepeque	55 Artifacts	37.9%
El Chayal	72 Artifacts	49.6%
Ixtepeque	14 Artifacts	9.7%
Media Cuesta	2 Artifacts	1.4%
Pachuca	2 Artifacts	1.4%
	145 Artifacts	100.0%

Early Classic Period (A.D. 250 - 600)

San Martin Jilotepeque	12 Artifacts	4.4%
El Chayal	208 Artifacts	77.1%
Ixtepeque	10 Artifacts	3.7%
Pachuca	30 Artifacts	11.1%
Tulancingo	1 Artifact	0.4%
Otumba	4 Artifacts	1.5%
Altotonga	1 Artifact	0.4%
Ucareo	2 Artifacts	0.7%
Unknown	2 Artifacts	0.7%
	270 Artifacts	100.0%

Late Classic Period (A.D. 600 - 800)

San Martin Jilotepeque	15 Artifacts	3.7%
El Chayal	311 Artifacts	77.7%
Ixtepeque	57 Artifacts	14.2%
Tajumulco	1 Artifact	0.3%
Media Cuesta	1 Artifact	0.3%
Pachuca	2 Artifacts	0.5%
Tulancingo	2 Artifacts	0.5%
Otumba	3 Artifacts	0.8%
Zaragoza	2 Artifacts	0.5%
Ucareo	1 Artifact	0.3%
Zinapecuaro	2 Artifacts	0.5%
Unknown	3 Artifacts	0.8%
	400 Artifacts	100.0%

Terminal Classic Period (A.D. 800 - 1000)

San Martin Jilotepeque	12 Artifacts	6.1%
El Chayal	130 Artifacts	66.0%
Ixtepeque	40 Artifacts	20.3%
Zacualtipan	1 Artifact	0.5%
Zaragoza	9 Artifacts	4.6%
Altotonga	2 Artifacts	1.0%
Zinapecuaro	1 Artifact	0.5%
Unknown	2 Artifacts	1.0%
	197 Artifacts	100.0%

Early Postclassic Period (A.D. 1000 - 1250)

San Martin Jilotepeque	4 Artifacts	6.7%
El Chayal	10 Artifacts	16.7%
Ixtepeque	37 Artifacts	61.7%
Pachuca	4 Artifacts	6.7%
Otumba	1 Artifact	1.7%
Zinapecuaro	2 Artifacts	3.3%
Unknown	2 Artifacts	3.3%
	60 Artifacts	100.1%

Table 15. Continued.

Late Postclassic Period (A.D. 1250 - 1550)

San Martin Jilotepeque	1 Artifact	0.9%
El Chayal	15 Artifacts	13.3%
Ixtepeque	91 Artifacts	80.5%
Pachuca	4 Artifacts	3.5%
Pico de Orizaba	1 Artifact	0.9%
Unknown	1 Artifact	0.9%
	113 Artifacts	100.0%

least Middle Preclassic to Late Postclassic times. They also indicate that the major routes along which the obsidian moved may have changed at least twice.

Summary

It has been shown that obsidian was used in the Lowland Maya area from at least Middle Preclassic times to the end of the Postclassic period. Its importance can be seen by the amount of effort that was put forth to transport the obsidian from highland Guatemala, and in some cases Mexico, to the Maya Lowlands. These exchange routes were long and difficult and the fact that they were being used indicates the importance of obsidian in particular and of exchange in general. It appears that both Cerros and Yaxchilan occupied important positions along these trade routes. During Late Preclassic times Cerros probably helped supply the large interior sites with coastal commodities such as shells and fish in exchange for obsidian. During Late Classic times Yaxchilan was in a position to control the flow of commodities up and down this part of the Usumacinta River and the obsidian data indicate that obsidian from Highland Guatemala was probably one of the items being traded along the river.

It is hoped that as research and technology progress, analyses of other items that were important in the exchange networks such as jade will become as valuable as obsidian in the study of exchange. As more commodities can be used to study the source of traded items the routes over which the items moved and the mechanisms and social conditions of exchange will begin to become more clear.

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Discussion with Reviewers

R.L. Johnson: It is mentioned that spectral overlaps were corrected. What were they and how was this done? (Specifically, for Zr and Ba). What spectral overlaps were corrected and by what method? Could the accuracy of the Zr data in Table 2 be improved by another correction method?
Author: Corrections were made for spectral overlap by subtracting the contributions of any overlapping peaks (e.g. Sr $K\beta$ overlaps Zr $K\alpha$). The intensity of the overlapping peak is assumed to be linearly proportional to the intensity of a second clear peak for that element. For example, the intensity of the Sr $K\beta$ peak is assumed to be linearly proportional to the intensity of the Sr $K\alpha$ peak. The spectral overlap ratio was determined on a pellet of pure quartz to which a 0.006 gram spike of pure reagent had been added. The ratio was determined for each element where spectral overlap was a problem for the set of elements used in the obsidian analyses.

The spectral overlap correction factor (S) for Zr, as determined on a quartz sample containing no Zr and a spike of $SrCO_3$ is:

$$S = P_{net}\ (Zr\ K\alpha)/P_{net}\ (Sr\ K\alpha) = 0.183$$

since any observed intensity at the Zr $K\alpha$ position is due to overlapping by the neighboring Sr $K\beta$ peak. Correction for spectral overlap was made using the same method for Nb, Y, Ba, and Ti.

Also, the accuracy of the Zr data probably could be improved by using a molybdenum X-ray tube instead of a tungsten tube. However, a molybdenum tube was not available for these analyses.

R.L. Johnson: Unless a substantial dilution is made during sample preparation, poor results are obtained when using a simple linear regression for Na_2O, TiO_2, MnO and Fe_2O_3. The normal procedure for these elements is to use a borate fusion process and about a 10:1 dilution. Otherwise some other mathematical correction of the strong interelement effects is necessary.
Author: It is true that normally when the above elements are analyzed the samples are prepared using a borate fusion process. However, since most obsidians are quite similar in their major element composition, and because the international rock standards used approach this same composition -- it is possible to ignore absorption coefficients and enhancement effects (Bertin 1970; Hutchison 1974).

J.A. Minkin: Do the assignments of the obsidian artifacts to geologic sources based on the XRF analytical method agree well with determinations for the same or similar samples by other methods of analysis? What method was used for the analyses carried out at the Lawrence Berkeley Laboratory?
Author: The assignment of the obsidian artifacts to the geologic sources generally agrees with results of analyses of similar types of collections that have been analyzed by others (see Tables 8 - 14 for a comparison of results and bibliographic references). The method used for the analysis of obsidian artifacts at the Lawrence Berkeley Laboratory is X-ray fluorescence with neutron activation analysis used to confirm source assignments or to determine the source if unable to do so using X-ray fluorescence (Moholy-Nagy et al. 1984).

G. Remond: All trace element analyses are performed by means of XRF which is a well-known method used on a routine basis for chemical analysis of ores and rocks. Thus, the discussions on the principle, the data acquisition and reduction procedures must be removed from the text (as well as Fig. 2). The analytical approach used in the case of obsidian materials has already been extensively discussed by the author as indicated in the references section. Only a brief summary of the experimental conditions used in the present study should be added as a short note at the end of the discussions.
Author: It is felt that many reports of obsidian analysis of geologic sources and artifacts are of much less value than they could be because the authors have not reported the methods of analysis nor the parameters used for the analyses (see Ives 1975 for a discussion of this). In contrast, when results are published with a detailed description of the methods of analysis and the instrumental parameters used to obtain these results it is possible, not only to check the results but also to use them for comparison to one's own data. This information is of interest to many as indicated by the previous two discussions with reviewers.

Reviewer #1: It is suggested that the abundances of the oxides be converted to those of the corresponding elements, in order to facilitate the use of the data by the reader, and to conform with much of the current usage in the literature.
G. Remond: For homogeneity all quantitative data must be given in terms of elemental or oxide

weight but not as a mixture fo both (Ba, TiO_2, MnO, Zr...).
Author: The results of analysis have been reported both as the element (Rb, Sr, Y, Zr, Nb and Ba) and as the oxide (MnO, Fe_2O_3, TiO_2, Na_2O) to conform to the method of reporting these elements in the geological literature. Also this is the way the data are reported in the journals reporting the values of the international rock standards (Flanagan 1973, 1976; Fabbi and Espos 1976; Steele 1979).

Reviewer #1: The ternary graphs have been used in the past, but do not contribute much to modern data interpretation used by Nelson. Figures 3 and 4 consequently could be dispensed with, as well as the corresponding descriptive text.
Author: The ternary graphs are used to help those not familiar with obsidian sourcing to visualize how the sources relate to and differ from each other.

Editor: From where can one obtain a copy of Jones, 1979; Nelson, 1981a and b and Rovner, 1981?
Author: I can provide anyone interested with a copy of these references.